THE EFFECT OF THE NUMBER AND SPACING OF ELEMENTS ON THE EFFICIENCY OF LASA BEAMS

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TELEDYNE, INC.

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Nuclear Test Detection Office
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ABSTRACT

LASA short-period recordings of 8 teleseismic earthquakes were prefiltered and beamsteered on P-wave arrivals across the 200 km. aperture to establish the relationship between sensor spacing and beam efficiency in terms of noise reduction, signal loss, and S/N ratio improvement.

Results show that the combined effect of increasing the number of elements in a beam while simultaneously reducing inter-sensor spacing is to produce progressively less rms noise reduction and S/N gain relative to $N^{\frac{1}{2}}$.

The study further shows that beamforming each of the events in two ways, e.g., with 51 and 525 inputs, produces an average signal loss of ~4 db. Moreover, beaming the smaller number of traces reduces rms noise and improves S/N only about 1 db less than the 525-element beam. For the 51-element beam, the minimum sensor spacing was 6 km., the distance at which the short-period noise at LASA becomes incoherent.

INTRODUCTION

This analysis was conducted in support of the VELA Seismological Center in an attempt to evaluate the effect of inter-sensor spacing on the efficiency of LASA beams. Specifically, we are interested in preserving the 200 km. aperture while determining the amount of signal loss, rms noise reduction, and signal-to-noise gain which is produced by beamforming various combinations of LASA traces. Our basic procedures include prefiltering, time-shifting, and summing.

The data are short-period recordings of P waves from eight teleseismic earthquakes which occured during the period 21 November 1965 to 22 April 1966. These events, which represent a subset of those reported earlier by Chiburis and Hartenberger (1966), are described in Table 1. Source parameters were taken from P.D.E. cards published by the USC&GS.

PROCEDURE

Each seismogram used in this study was detrended to remove the mean, demagnified to convert digital counts to equivalent earth motion at 1 cps, and prefiltered to the band 0.4 - 3.0 cps. In forming the beams, subarray data were time-shifted to the earliest arrival on the basis of apparent phase velocity and station-to-epicenter azimuth. Array data were shifted by applying travel-time differences corrected by observed average travel-time anomalies, for each epicentral area.

Signal amplitude is defined as half the maximum peak-to-trough amplitude occuring within an 8-second window. Noise amplitude is defined as the root-mean-square value obtained in a 50-second window ahead of the P arrival. Gains and losses, in decibels, are computed from the following formula:

$$\text{db} = 20 \log \left[\frac{\text{value on beam output}}{\text{average input}}\right]$$

BEAMS

Seismograms from one of the eight events, the 19 March 1966 Hokkaido earthquake, were beamformed six times. The beams were composed of 17, 34, 51, 68, 119, and 525 channels, corresponding to approximate minimum intersensor spacings, Δ, of 12, 6, 6, 3, 3, and 0.5 kilometers. Figure 1 shows the 17 subarrays which contributed traces to the beams. The four subarrays comprising the "B" ring have been eliminated. Moreover, aside from the number of elements in the beams, all parameters for signal alignment were held constant, e.g., phase velocity, azimuth, travel-time differences, anomalies, and the time windows of the signal and the rms noise, were not changed. Figures 2 through 6 illustrate subarray configurations for the first five beams, while Figures 7 and 8 show array and subarray configurations for the beam containing all 525 inputs.

Recordings of each of the eight events shown in Table 1 were beamsteered twice by using 51 traces in the first beam and 525 channels in the second. In the case of the 51-element beam, three seismograms from each of the 17 subarrays were used (Figure 4). Minimum intersensor spacings for the 51 and 525-element beams were 6 kilometers and 0.5 kilometers, respectively. The amount of signal loss, rms noise reduction, and S/N produced by the events were averaged to obtain values which are discussed in the next section.

RESULTS

Figures 9, 10, and 11 are plots of signal loss, rms noise reduction, and S/N gain. resulting from beamforming the Hokkaido event. Each figure shows gain or loss in decibels as a function of the number of beam inputs, N. As shown in Figure 9, the signal loss is 2 db for the 17-element beam, whereas the amount of signal loss for beams containing 34 or more traces is 3 db. This infers that imprecisions in beamforming the entire LASA are more significant than the inaccuracies resulting from time-shifting subarray data.

Figure 10, which shows rms noise reduction as a function of N for the Hokkaido event, illustrates that as N increases and Δ decreases, the amount of noise reduction becomes less favorable relative to $N^{\frac{1}{2}}$. In fact, the advantage of the 525-element beam with respect to the much smaller 51-element beam is only 1 db. Moreover, the 119-trace beam performs equally as well as the largest beam.

S/N gain as a function of N for the Hokkaido earthquake is shown in Figure 11, in which the results reflect the combined effect of signal loss and noise reduction as discussed above; our interpretation need go no farther.

Figures 12 through 14 are plots of average values for signal loss, rms noise reduction, and S/N gain, as a function of N. We repeat that these values represent average results obtained from our set of eight events. The average signal loss shown in Figure 12 is about 4 db for both the 51-element and 525-element beams.

The average noise reduction produced by beamforming 51 channels, Figure 13, is very close to $N^{\frac{1}{2}}$ and only 1 db less than that produced by the larger beam. Again we see that the combined effect of increasing N and simultaneously reducing Δ to values less than 6 km. is to produce less noise cancellation relative to $N^{\frac{1}{2}}$. Previous work (Hartenberger and Shumway 1967) has shown that for spacing of 6 km. or more, the short-period noise at LASA is essentially incoherent.

As shown in Figure 14, S/N gain yielded by beaming 51 traces is only 1 db less than that produced by beamforming all 525 channels.

Figure 15 shows the rms noise level, in mμ, as a function of event number. The solid dots represent values taken from outputs of 525-element beams, while the open circles are corresponding values for the smaller beam. The average noise level on the larger beam is 0.21 mμ, whereas the smaller beam average is 0.25 mμ.

CONCLUSIONS

In an SDL study LASA prefiltered short-period recordings of 8 teleseismic events were beamsteered on the P arrival using a variable number of beam inputs. Our objective was to determine the efficiency of the beams with respect to the number of inputs and the spacing of sensors contributing to the beams. The following conclusions are based on that analysis:

1. The net effect of increasing the number of beam inputs while simultaneously decreasing sensor spacing is to produce progressively less rms noise reduction and S/N gain, relative to $N^{\frac{1}{2}}$.

2. Average signal loss amounts to 4 db. We attribute part of the loss (1 db?) to misalignment of P waves within subarrays. The remaining signal loss is due either to inaccurate array alignment or to differences in wave form across the LASA.

3. Beams composed of 51 traces reduce rms noise and improve S/N within 1 db of that produced by 525-element beams. The 51 elements were selected to have minimum sensor spacing greater than 6 km.

RECOMMENDATIONS

In the study described above we discarded the "B" ring subarrays in determining the efficiency of LASA 51-element beams and thereby preserved the original 200 km. aperture. We are equally interested, however, in more efficient arrays requiring lower initial installation costs and less maintenance. Therefore, another analysis is suggested which should include the following:

1. The comparison of the results of this study with those produced by beamforming 51 traces recorded over the smaller area covered by the A, B, C, D and E subarrays (100 km. aperture). Moreover, we would further reduce the array size

by beaming 51 channels derived from the A, B, C and D subarrays (30 km. aperture) for an additional comparison.

2. Nine sensors comprising the B and D rings of each subarray are being removed. This amounts to 189 sensors or 36% of the entire LASA. The effect of beaming outputs from the remaining 336 sensors (16/subarray) should be evaluated in the proposed study.

REFERENCES

Chiburis, E. F. and Hartenberger, R. A., 1966, "Signal-to-noise Ration Improvement by Time-Shifting and Summing LASA Seismograms", Report No. 164, Seismic Data Laboratory, Teledyne Incorporated, Alexandria, Virginia.

Hartenberger, R. A. and Shumway, R. H., 1967, "A Beamforming Study Using Outputs from the Extended E3 Subarray at the Montana LASA", Report No. 198, Seismic Data Laboratory, Teledyne Incorporated, Alexandria, Virginia.

EVENT NAME	DATE	ORIGIN TIME	LOCATION		DISTANCE		DEPTH IN KM	APPARENT VELOCITY	BACK AZIMUTH	CAL DATE	USC&GS m	NO. OF OUTPUTS USED
			LAT	LONG	DEG	KM						
KURILE	21 Nov 65	06:10:56.0	48.4N	154.7E	62.1	6902	33	16.6	311.9	11/21/65	4.7	525
NO. COLOMBIA	21 Dec 65	12:25:43.0	06.9N	73.0W	48.8	5429	172	14.4	133.7	12/21/65	4.9	525
ALASKA PENN.	30 Dec 65	03:02:59.0	54.1N	160.2W	34.5	3831	33	12.9	302.6	12/30/65	4.5	525
SO. PERU	30 Dec 65	06:16:03.9	16.85	71.2W	70.6	7854	118	18.2	144.4	12/30/65	5.7	525
CHIAPAS, MEX.	22 Jan 66	07:36:49.3	17.4N	94.1W	30.9	3434	139	12.6	157.0	1/22/66	4.9	525
HOKKAIDO	19 Mar 66	08:11:40.0	43.3N	145.8E	70.1	7794	11	18.1	312.4	3/19/65	5.6	525
NO. COLOMBIA	21 Apr 66	08:18:23.9	06.9N	73.1W	48.8	5424	152	14.4	133.8	4/21/66	4.8	525
KODIAK	22 Apr 66	10:15:51.0	56.9N	151.8W	29.5	3275	33	12.6	307.2	4/22/66	4.9	525

Table 1. Source data

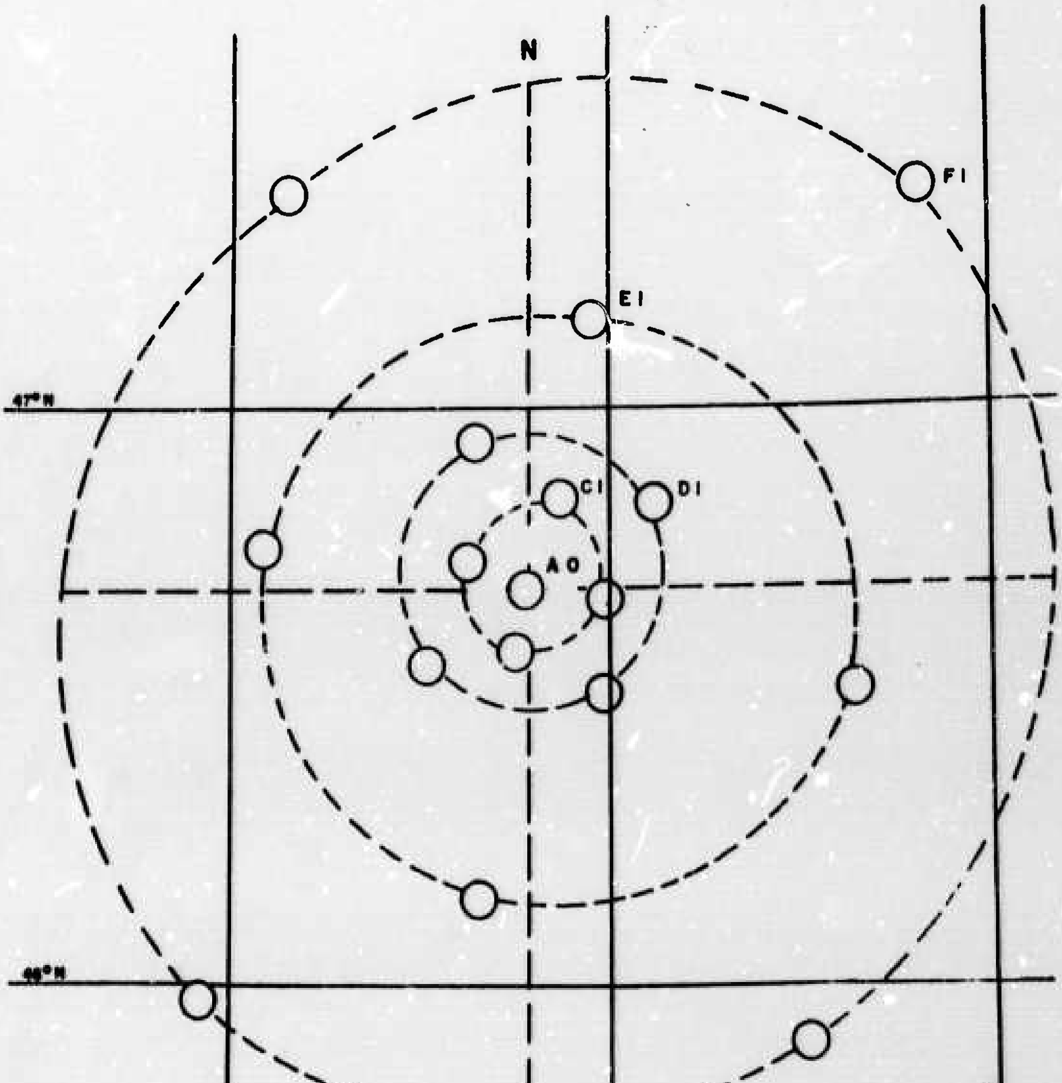

Figure 1. LASA Configuration for N ≠525

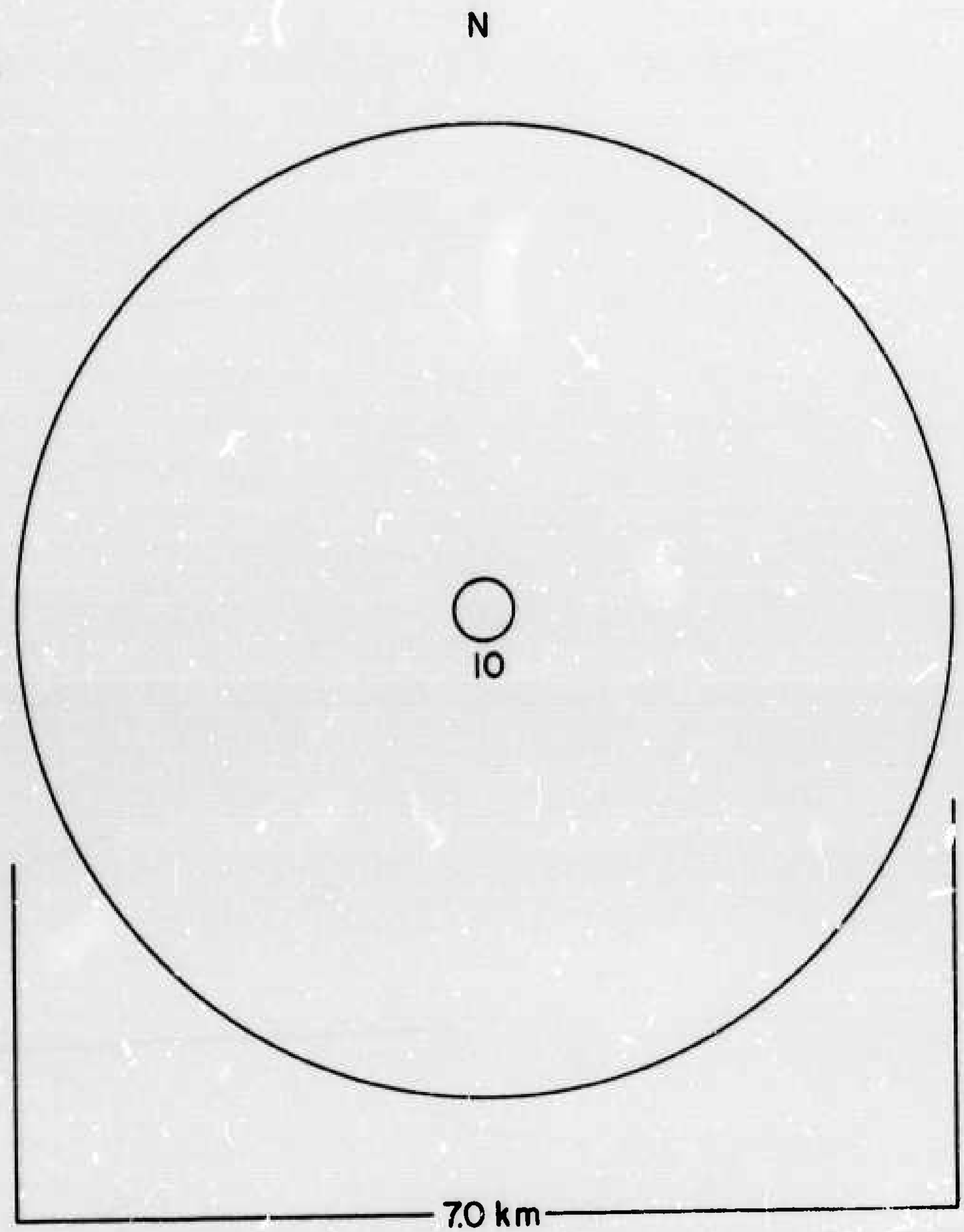

Figure 2. LASA Subarray Configuration for N=17

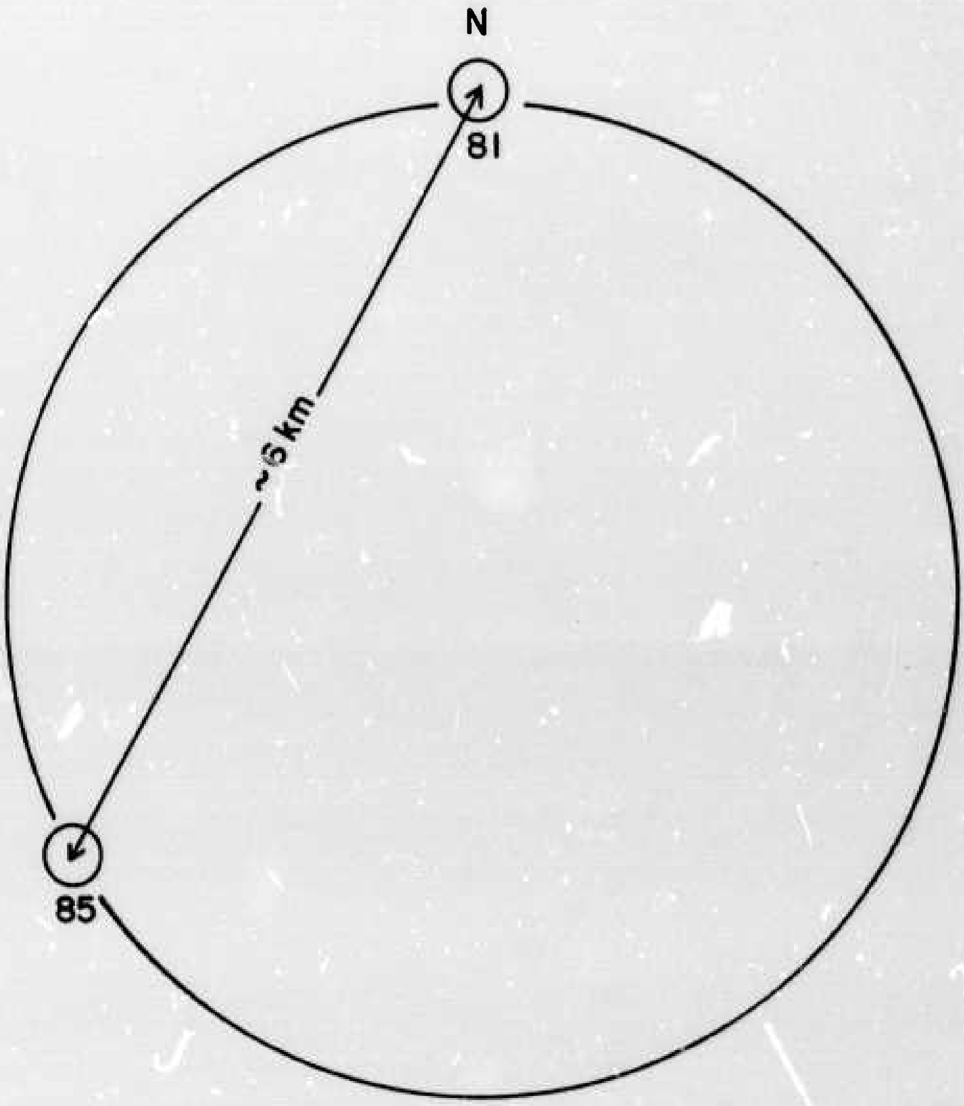

Figure 3. LASA Subarray Configuration for N=34

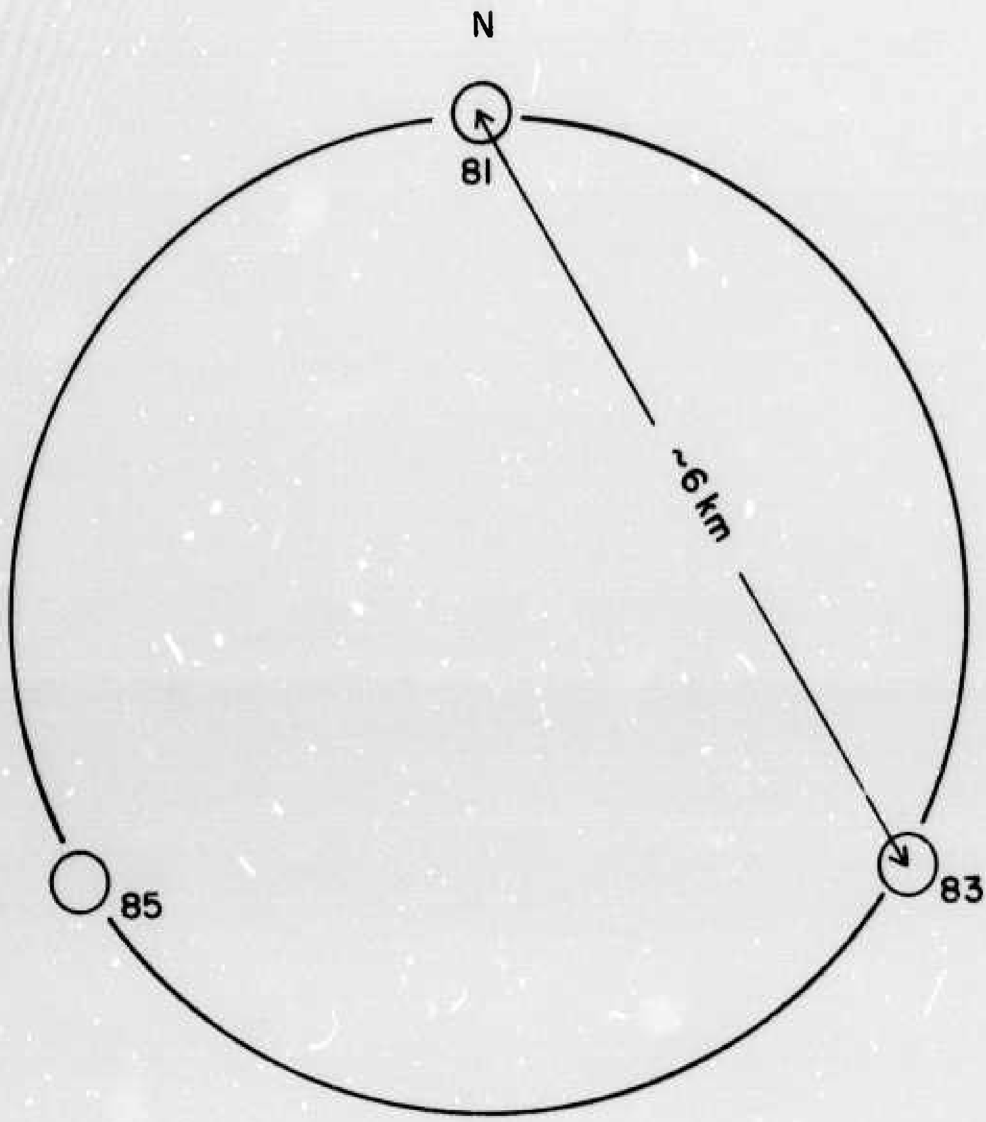

Figure 4. LASA Subarray Configuration for N=51

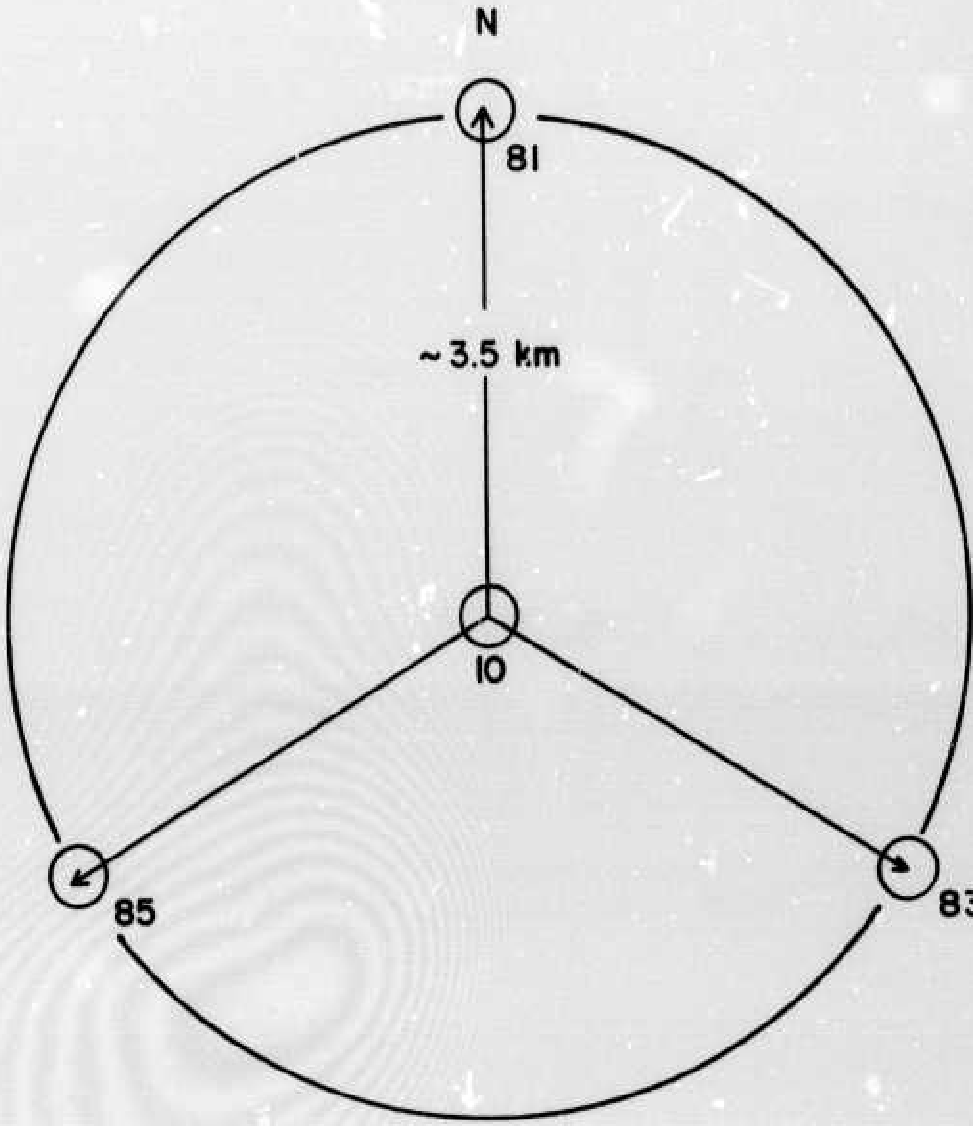

Figure 5. LASA Subarray Configuration for N=68

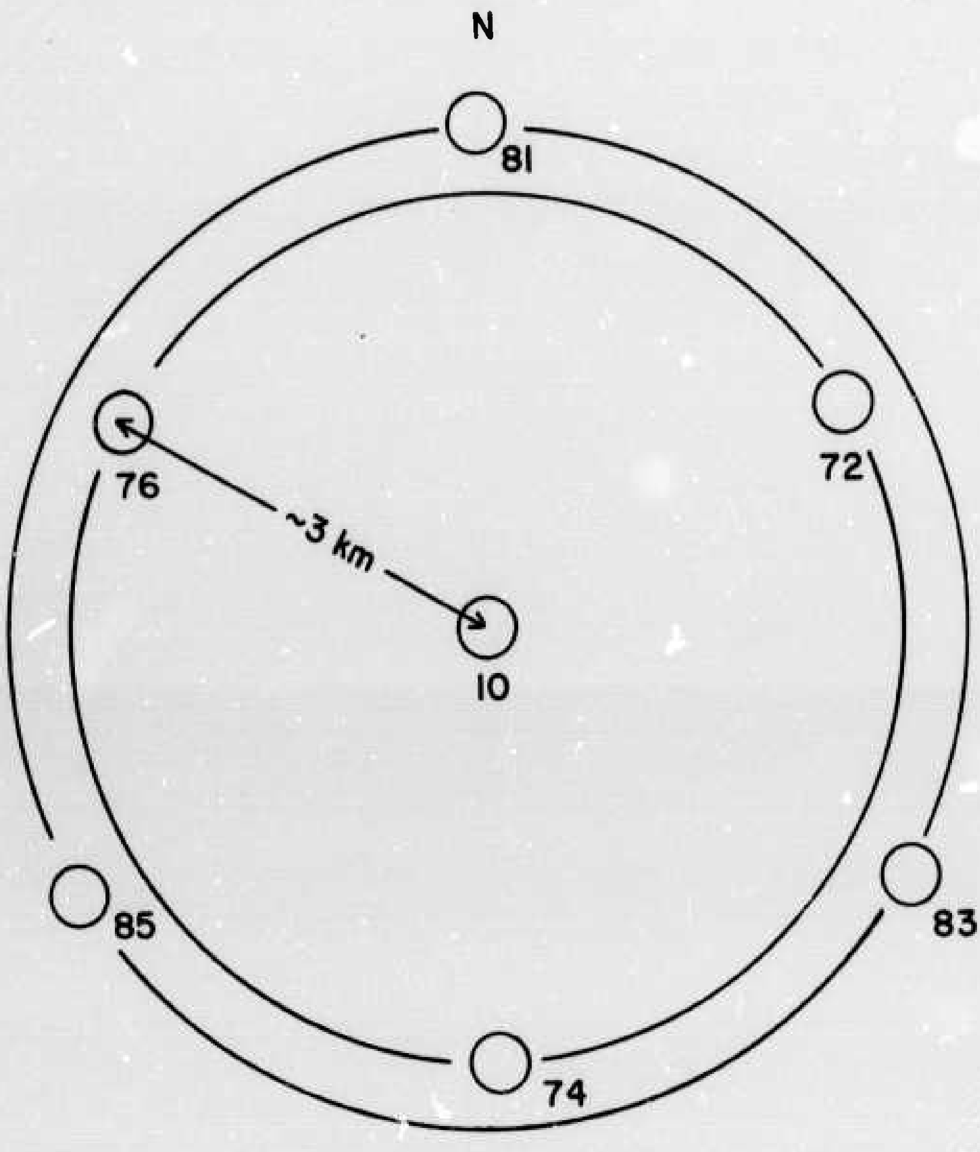

Figure 6. LASA Subarray Configuration for N=119

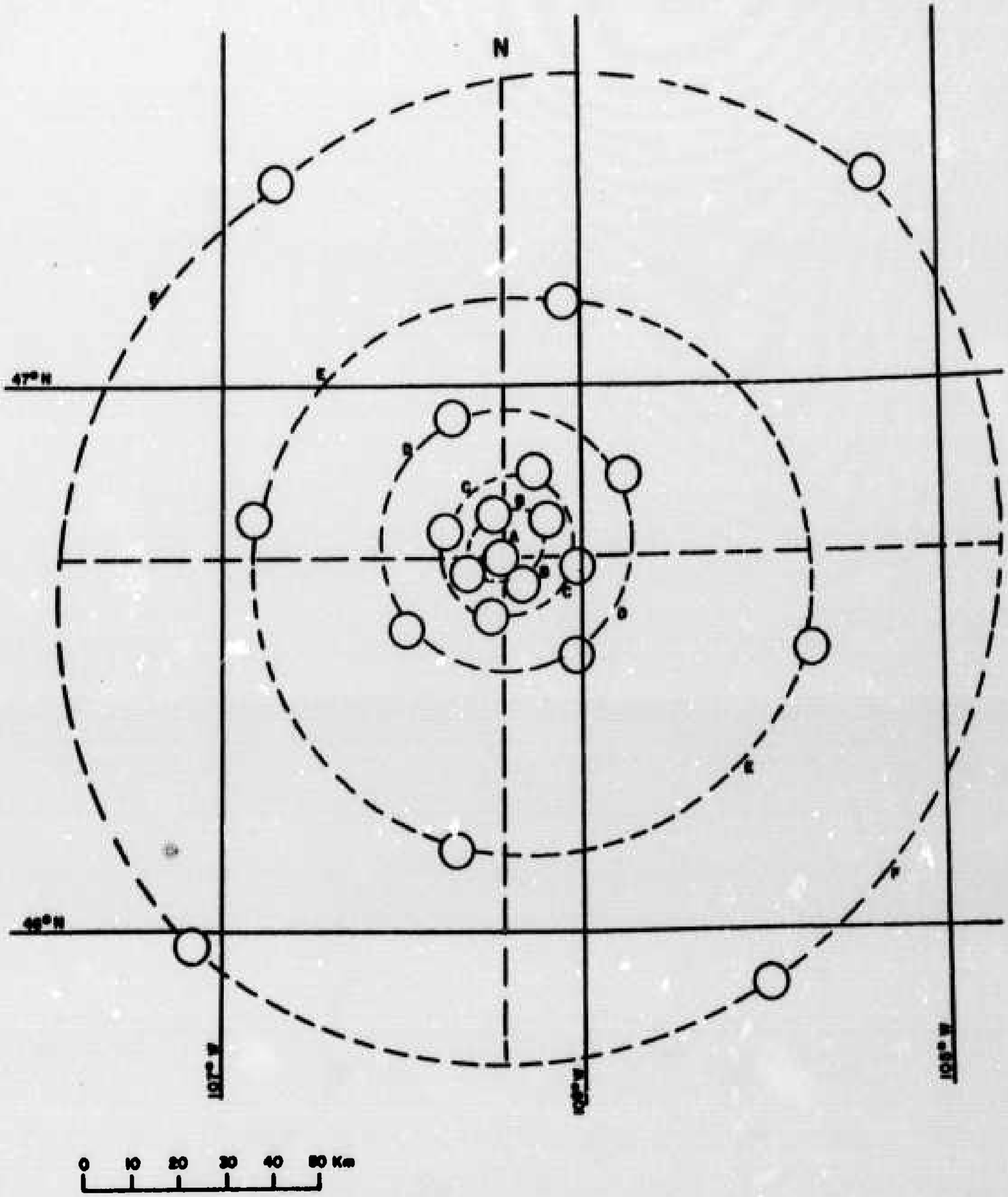

Figure 7. LASA Configuration for N=525

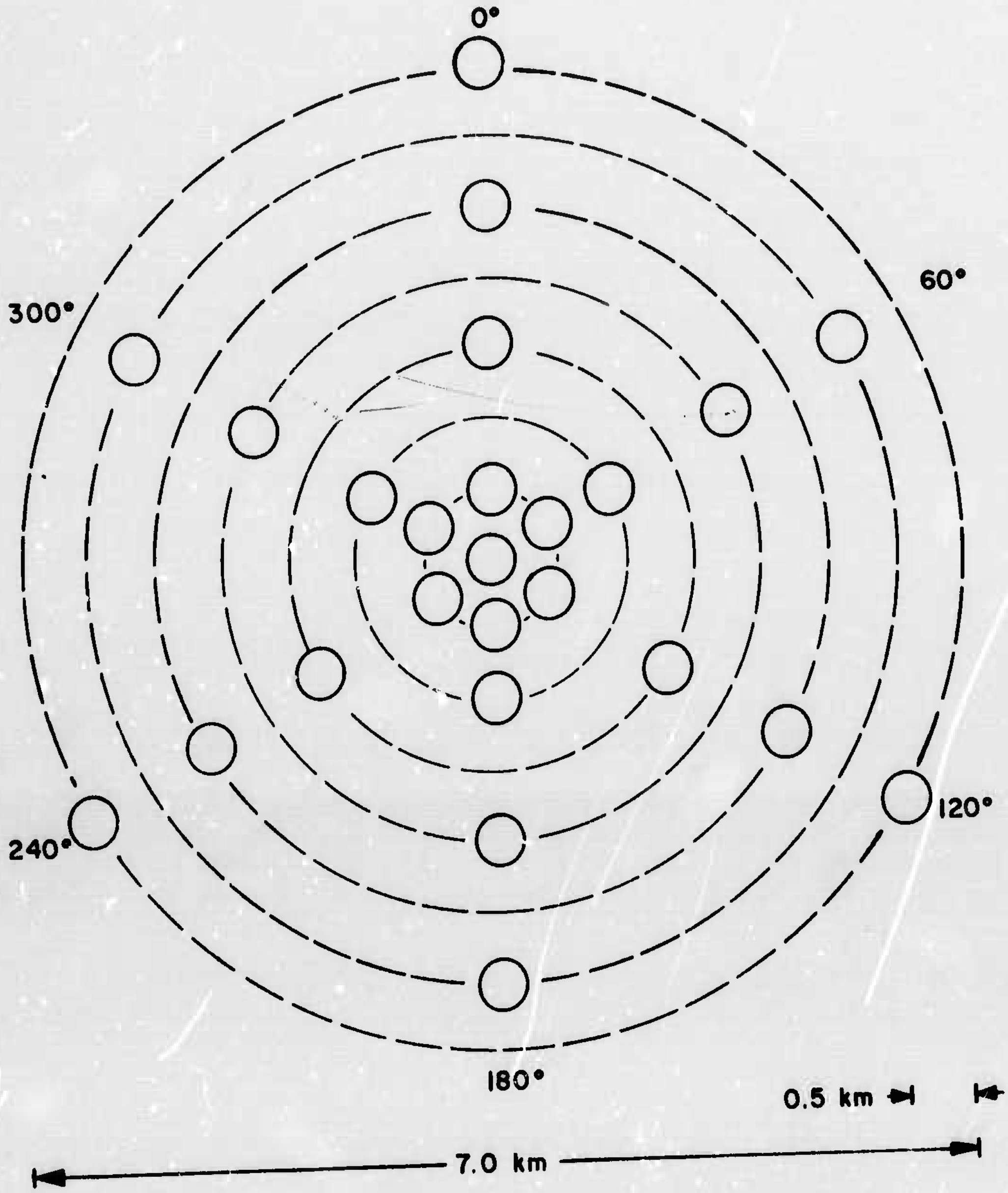

Figure 8. LASA Subarray Configuration for N=525

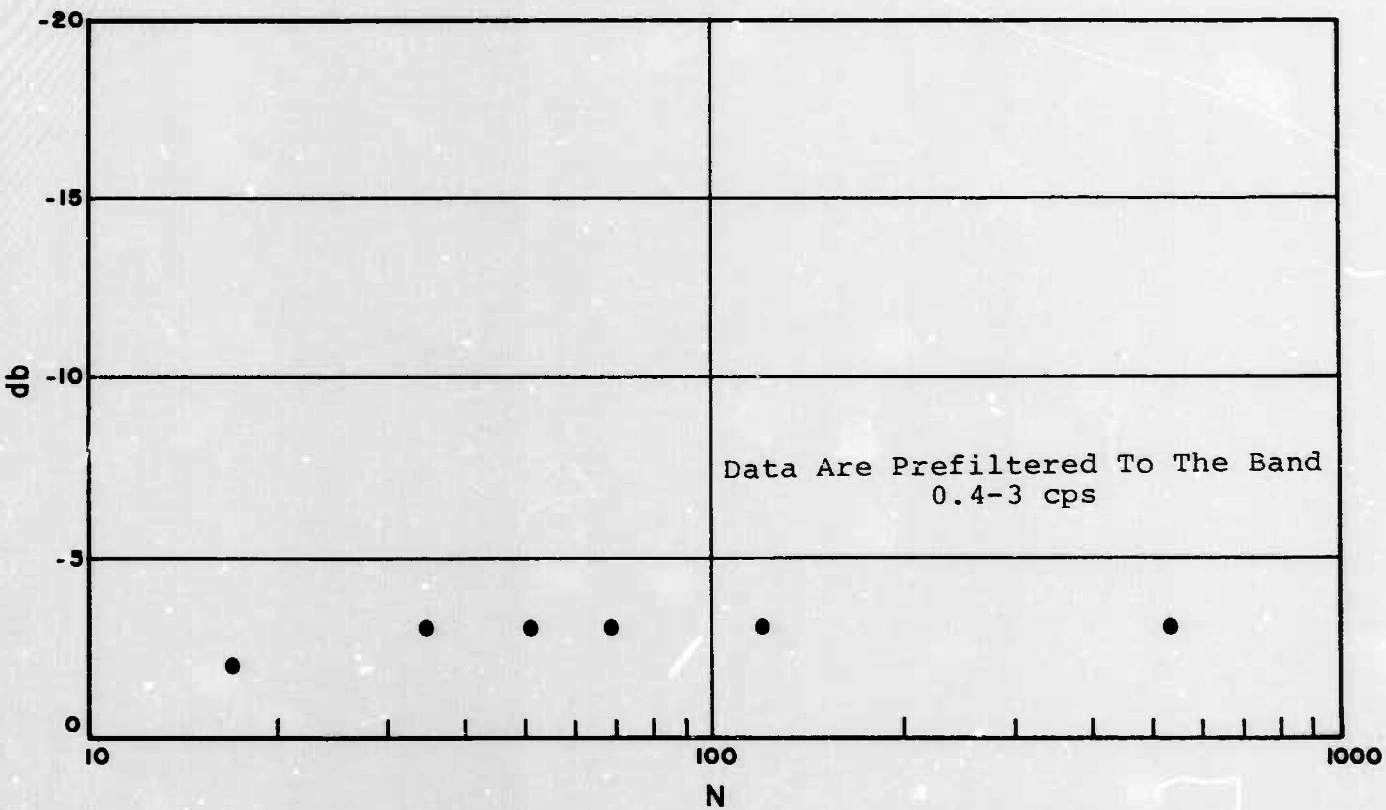

Figure 9. Signal Loss by Beamforming LASA Recordings Of The 19 March 1966 - Hokkaido Earthquake

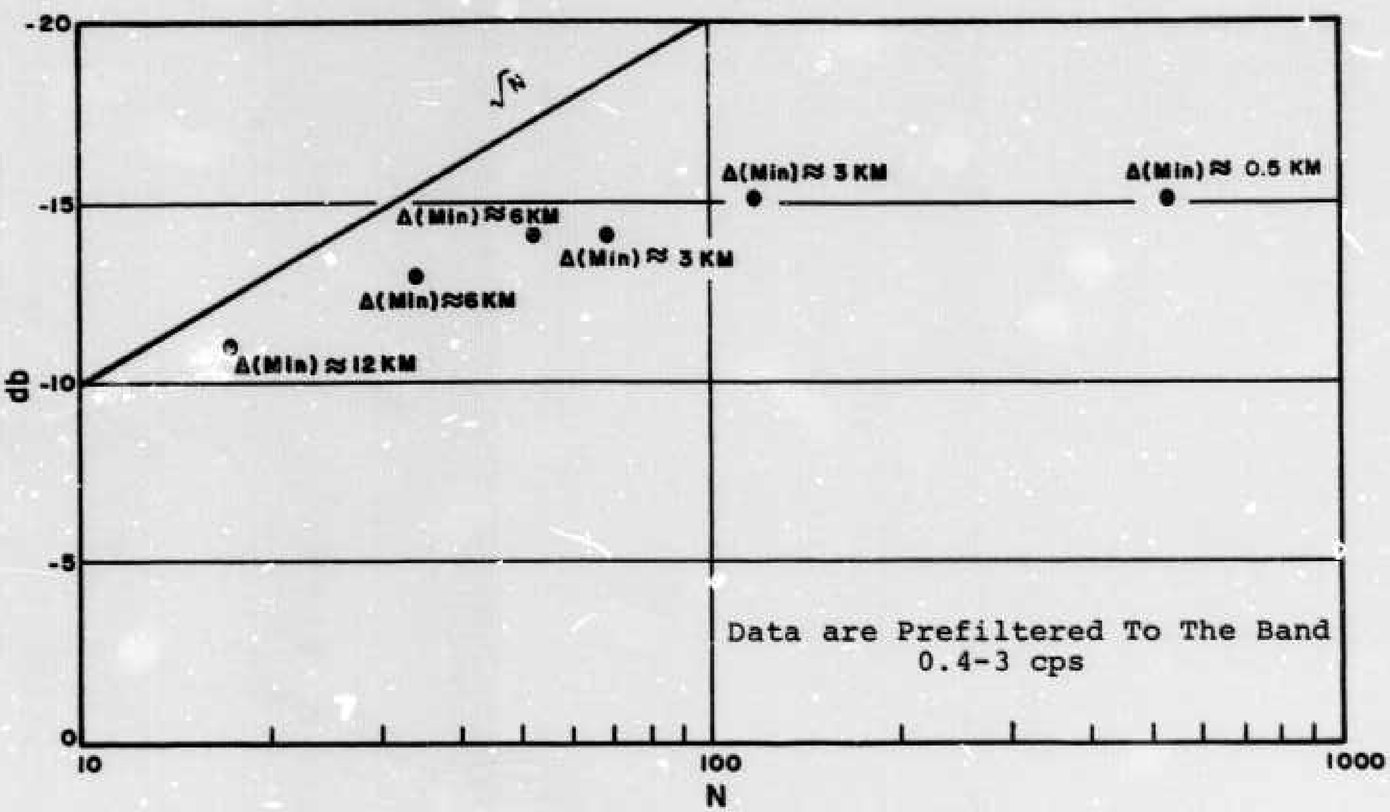

Figure 10. RMS Noise Reduction by Beamforming LASA Recordings of the 19 March 1966 Hokkaido Earthquake

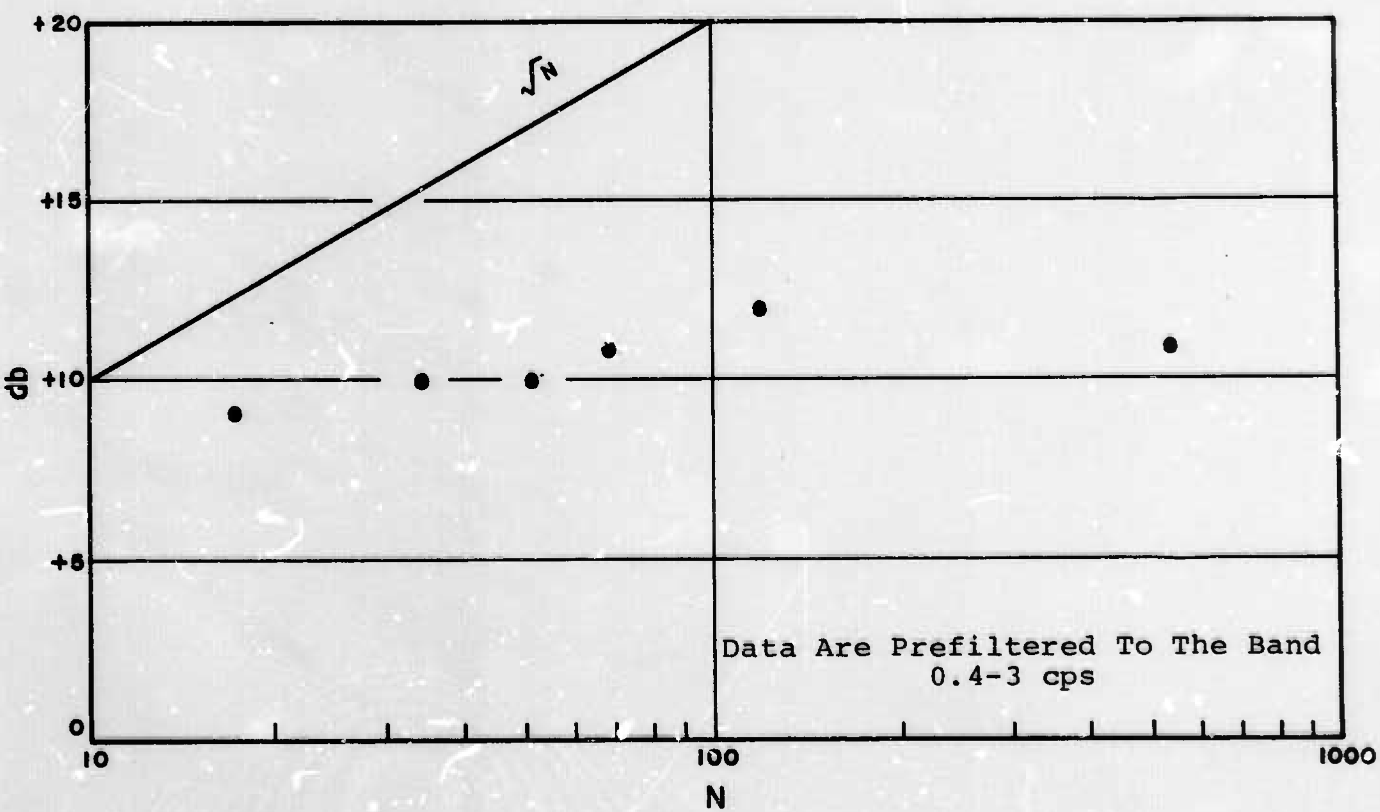

Figure 11. S/N Improvement by Beamforming LASA Recordings of the 19 March 1966 Hokkaido Earthquake

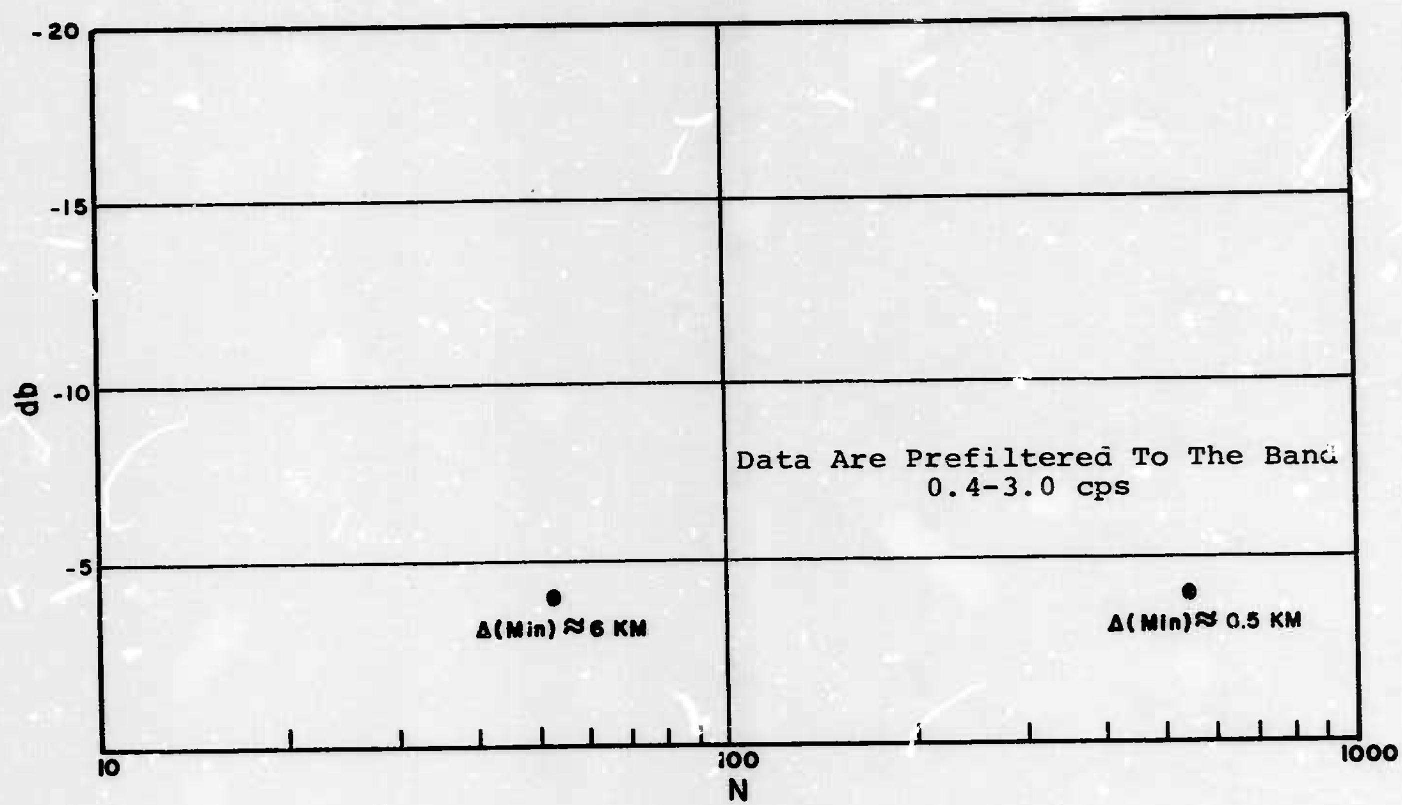

Figure 12. Average Signal Loss By Beamforming LASA Seismograms

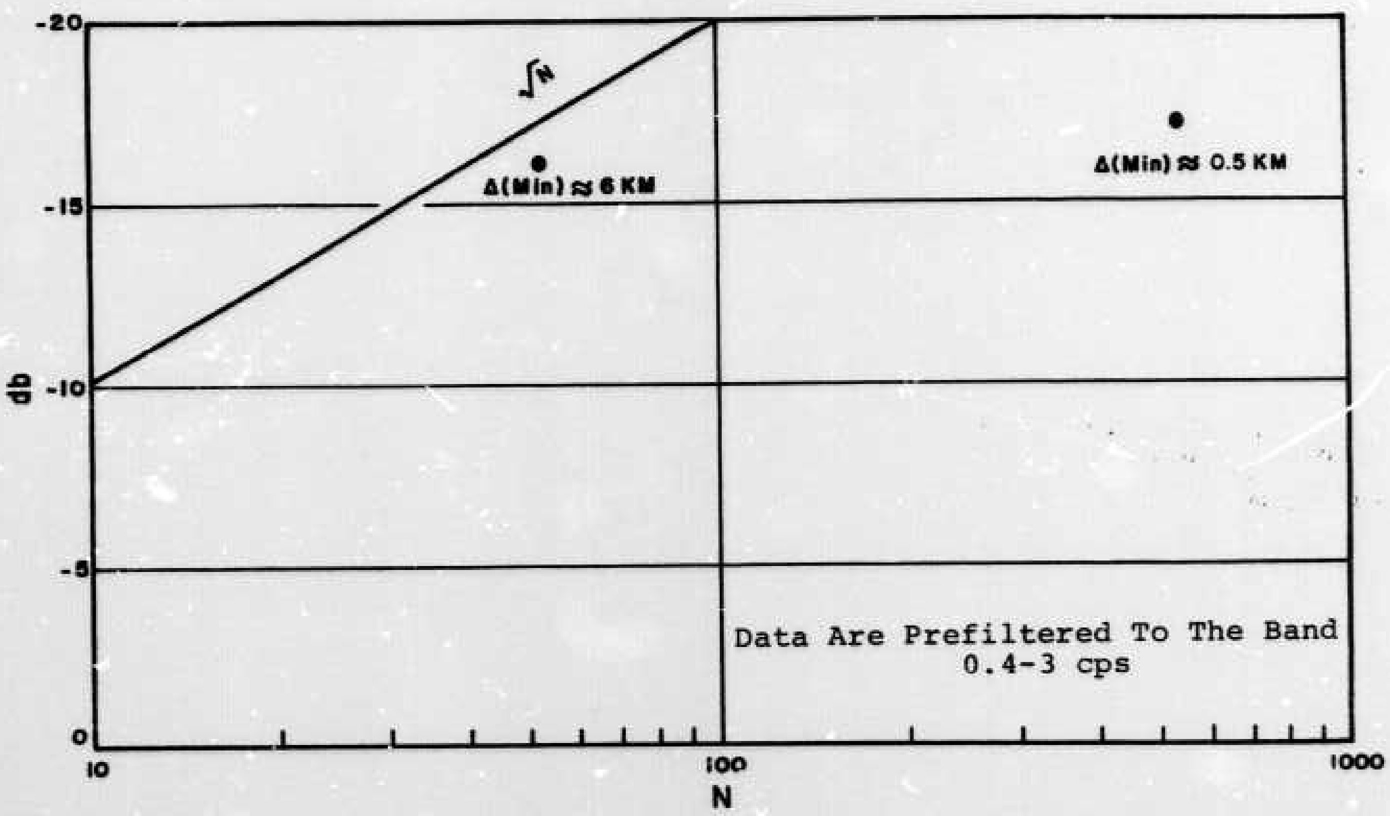

Figure 13. Average RMS Noise Reduction By Beamforming LASA Seismograms

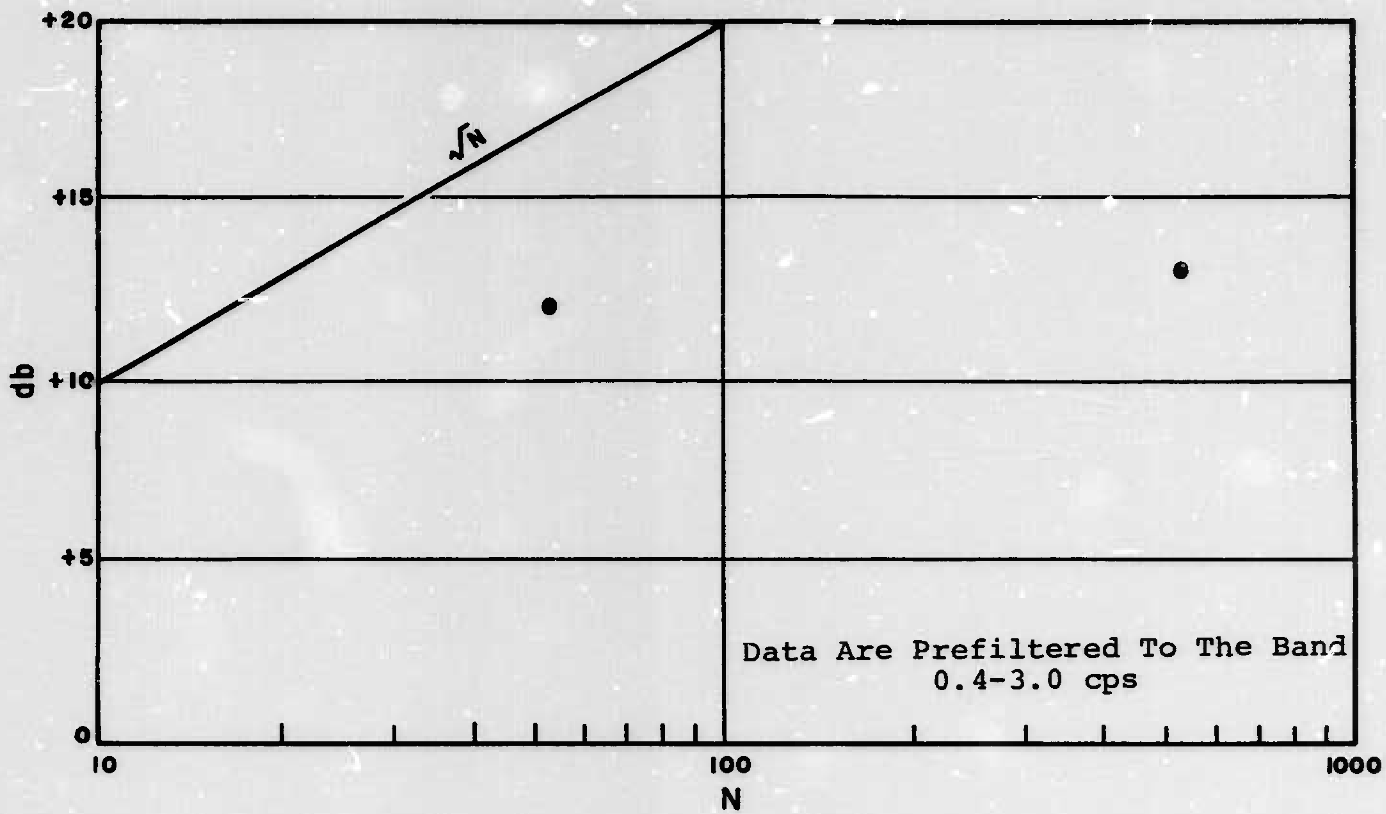

Figure 14. Average S/N Improvement by Beamforming LASA Seismograms

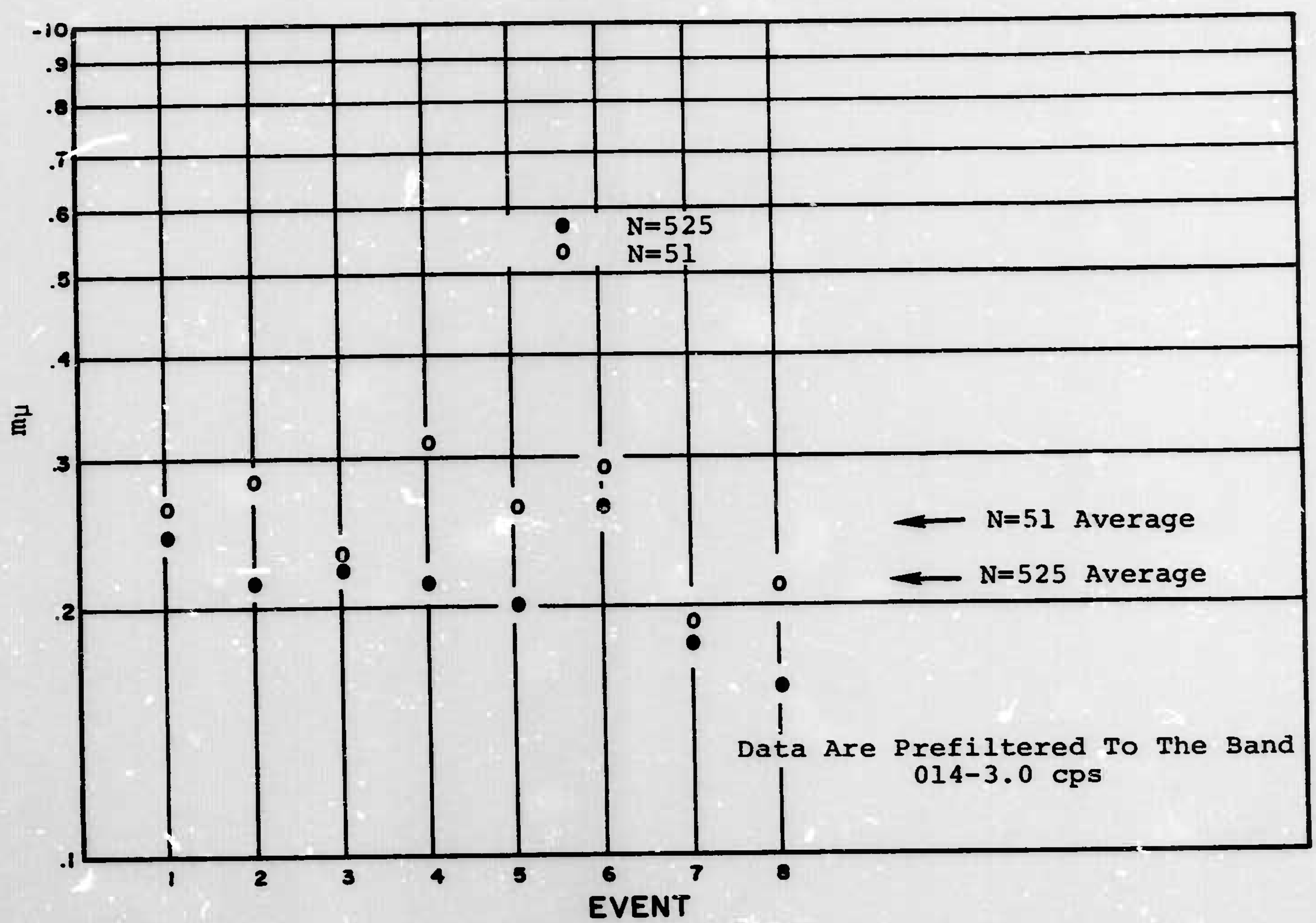

Figure 15. RMS Noise Levels on LASA Beams

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The study further shows that beamforming each of the events in two ways, e.g., with 51 and 525 inputs, produces an average signal loss of approximately 4 db. Moreover, beaming the smaller number of traces reduces rms noise and improves S/N only about 1 db less than the 525-element beam. For the 51-element beam, the minimum sensor spacing was 6 km., the distance at which the short-period noise at LASA becomes incoherent.

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Array efficiency						
Signal						
rms noise						
Signal-to-noise ratio						

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